A semi quadruped walking robot - first experimental results

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ABSTRACT

SemiQuad is walking robot prototype with a platform and two two-link legs. Thus, it is five-link mechanism. Front leg models identical motions of two quadruped's front legs, rear leg models identical motions of two quadruped's rear legs. We call this robot also as "virtual" quadruped. The mechanism is driven by four DC motors. Its control system comprises a computer, hardware servo-systems and power amplifiers. The locomotion of the prototype is planar *curvet* gait. In the double support our prototype is statically stable mechanism. In the single support it is unstable and under actuated system. There is no fly phase. We describe here the scheme of the mechanism, the characteristics of the drives and the control strategy. The dynamic model of the planar walking is recalled for the double and single support phases. The designed control strategy overcomes the difficulties appeared due to unstable and under actuated motion in the single support. In the first experiments, the designed algorithm was successfully implemented.

1. INTRODUCTION

It is possible to distinguish three main families of the walking robots. Firstly, the static stable robots, their motion is such that the projection of the mass center is always inside the support polygon i.e, polygon formed by the stance feet. Only slow motions are achieved in the static stability mode. Secondly, the semi dynamic stable robots, their motion is such that the Zero Momentum Point (ZMP) is inside the support surface during some time-intervals [2]. The feet have a surface contact with the ground. The third family of the walking robots is composed of bipeds, or quadrupeds walking robots, which have sometime less than three point feet on the ground. These walking robots are under actuated mechanisms for some phases of the motion. A free rotation of the robot around the point contact or around the axe defined by the two point contacts is possible. Many papers are devoted to this kind of walking robots, for example to the bipeds, which are adapted to the human environment, see for example [7]. However the quadrupeds are also interesting objects of study, see [3]. There are several possible kinds of gait for a quadruped, for example, amble, trot, curvet [1, 5, 6, 8]. Usually two following half steps of a quadruped are not symmetric in the saggital plane.

The dynamical quadruped walking robots present an interesting challenge. They are useful due to their possibilities to transport payloads with fast displacement. For these reasons we decided to build a prototype, which is a semi quadruped or virtual quadruped. It has two legs, which are linked by a platform. In the saggital plane with a walking curvet gait it can be viewed as a quadruped robot using the virtual leg principle [1], if the motions of the front legs (respectively the motions of the rear legs) are synchronized.

The article is organized as follows: Section 2 describes our virtual quadruped mechanism. Section 3 gives a description of the experimental environment. A dynamical model of the mechanism is defined in Section 4. The control strategy is explained in Section 5. Section 6 presents the first experimental results. Section 7 contains our conclusion.

2. DESCRIPTION OF THE MECHANISM

A photo of *SemiQuad* is presented in Figure 1. The prototype is composed of a platform and two identical two-link legs with knees. The legs have passive (uncontrolled) feet extending in the frontal plane. Thus, the mechanism can fulfill planar walking only. So, only 2-D motion in the sagittal plane is considering. There are four electrical DC motors with gear reducers to actuate the joints between the platform and the thighs and the knee-joints. These four actuated joints of the robot are each equipped with one encoder to measure angular position. The angular velocities must be calculated, using the signals about the angular positions. The four encoders have 2000 pts/rev and are attached directly to the motor shaft. The absolute orientation of the support leg shin is given by potentiometer sensor, fixed to the lateral stabilisation device. It does not appear in Figure 1. The *speed of response* or *bandwidth* of each axis of the robot is determined by the transfer function of the mechanical power train (motors, gears) and the motor amplifiers that drive each motor. In the case of *SemiQuad* we have approximately a 53 Hz bandwidth in the mechanical portion of the axes and approximately 1.7 kHz for the amplifiers. Using dynamic simulations, we have chosen parameters of the prototype (the sizes, masses, inertia moments of the links), the convenient actuators. The lengths, masses and inertia moments of each link of *SemiQuad* and the parameters of the four actuators with their gear reducer are specified in Table 1. The gear ratio is 50. The maximal value of the torque in the output axe of each motor gear is 40 N.m.

	platform	thigh	shin	DC motor in Haunch	DC motor in knee
length in *m*	0.37	0.15	0.15		
mass in *kg*	0.57	0.47	0.40	2.82	2.74
inertia in $kg.m^2$	0.32	0.84	0.06	$3.25\ 10^{-5}$	$2.26\ 10^{-5}$

Table 1. Parameters of *SemiQuad*.

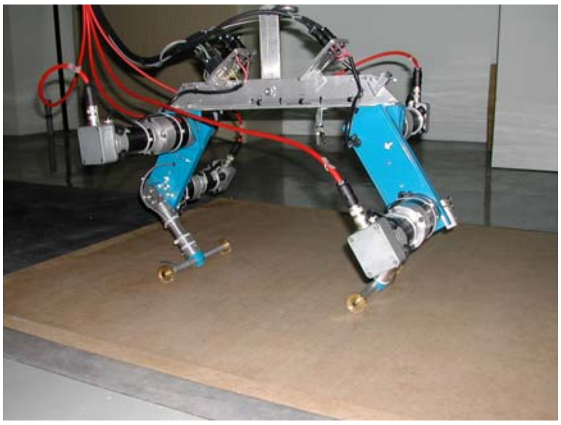

Figure 1. Semi Quadruped (virtual quadruped).

All pieces of *SemiQuad* are designed using a parametric DAO software. Then it is easier to make some improving modifications for the prototype or to build in future a version 2 of our prototype eventually.

SemiQuad is a two-legged mechanism as an anthropomorphic biped. But unlike a biped its body is a horizontal platform and the legs are linked to the ends of this platform. Unlike a biped the front leg is always in front of the *SemiQuad* and the rear leg is always behind. There is no a swap of the legs as during the biped walking.

3. EXPERIMENTAL ENVIRONMENT

To get the measurement data and to implement the control algorithm, a dSPACE system was selected as the real-time control platform. The low-level computation, digital-to-analog and analog-to-digital conversion, as well as the user interface are provided by the dSPACE package. The control computations were performed with a sample period of 5 ms (200 Hz). The software is developed in C language.

4. DYNAMIC MODEL

The models for single support and double support motions are presented in this Section.

4.1. Single Support Phase

Let the vector $\Gamma = (\Gamma_1, \Gamma_2, \Gamma_3, \Gamma_4)^*$ with four components denote the applied torques in the haunch and knee joints. Let $R_j(R_{jx}, R_{jy})$ be the force applied to the stance leg tip *j* – the ground reaction. Using the second Lagrange method, motion equations of the *SemiQuad* in the swing phase are obtained and they have the following well-known form for $j=1$ or 2:

$$A(q)\ddot{X} + H(q,\dot{q}) = D\Gamma + D_j(q)R_j \tag{1}$$

$$D_j^*(q)\ddot{X} + H_j(q,\dot{q}) = 0 \tag{2}$$

The two Cartesian coordinates of the platform mass center and the five orientation angles $[\alpha, \theta_1, \theta_2, \theta_3, \theta_4]^* = q$ of the legs and the platform define vector *X*. Here $A(q)$ is the symmetric, positive definite 7×7 matrix of kinetic energy; $H(q,\dot{q})$ is the 7×1 vector of the centrifugal, Coriolis and gravity forces; D is a 7×4 fixed matrix, consisting of zeros and units; $D_j(q)$ is a 7×2 matrix; $D_j^*(q)$ is the transposed matrix 2×7 of $D_j(q)$, $H_j(q,\dot{q})$ is a 2×7 matrix. Setting null acceleration condition (2) of a contact between the supporting leg tip and the ground implies that both abscise and ordinate of that leg tip do not change.

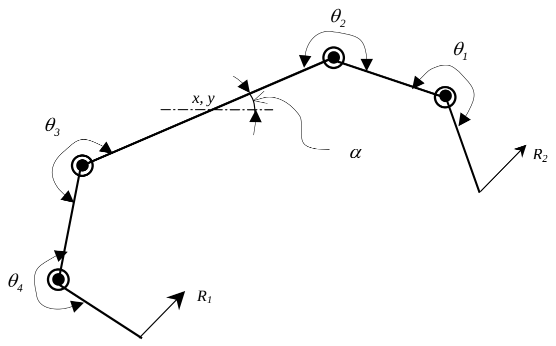

Figure 2. SemiQuad's Scheme.

Thus, in the single support the number of freedom degrees is five, but there are only four torques. This means that *SemiQuad* is under actuated mechanism in the single support motion. Also it is unstable during this motion.

4.2. Double Support Phase

In the double support, *SemiQuad* has both legs on the ground. Instead of matrix equations (1) and (2) we have the following matrix equations for this phase:

$$A(q)\ddot{X} + H(q,\dot{q}) = D\Gamma + D_1(q)R_1 + D_2(q)R_2 \tag{3}$$

$$\begin{bmatrix} D_1^*(q) \\ D_2^*(q) \end{bmatrix} \ddot{X} + \begin{bmatrix} H_1(q,\dot{q}) \\ H_2(q,\dot{q}) \end{bmatrix} = 0 \tag{4}$$

In the double support, *SemiQuad* has three degrees of freedom and four torques. In this phase, our walking robot is over-actuated. However it is static stable during double support motion.

5. CONTROL STRATEGY

By the analogy to the animal walk, the walk gait modeled here consists of alternating phases of single and double support. There is no a fly. *SemiQuad* must jump with front or rear leg to realize this walking gait. It is not possible to adopt another way without leg sliding. (Let us note, we can define a motion of *SemiQuad*, using only double support phase with sliding of the leg tips along the bearing surface.) Then we have to deal with the under-actuated problem in the single support. We tested this strategy in simulation [4] to study its feasibility. Let us consider a current half step *n*, which is composed of a double support and a single support on the rear stance leg. The next half step *n+1* is composed of another double support and a single support on the front stance leg. At the beginning of the current half step *n*, *SemiQuad* has to prepare its front leg tip to take off. Therefore, initially in the double support, *SemiQuad* transfers its mass center backward tracking suitable reference trajectories for the inter-link angles. After, also in the double support, the front leg bends in the knee and then it sharply unbends. As maximal as possible torque is applied to the front leg knee to unbend it. (At this time the front leg pushes the ground.) After we invert this torque and the front leg bends in the knee once more. At this time front leg tip looses its contact with the ground and the single support phase starts. In the single support of half step *n*, four torques are applied to the joints to track the reference trajectories. The reference trajectories are such that the distance between the leg tips becomes lager to the end of the single support. Due to this the front leg tip moves forward. The reference trajectory for each inter-link angle is a polynomial function of time, but before the impact, the desired inter-link angle becomes a constant. That way we are sure to get the desired final configuration of our prototype before the impact even the duration of the single support phase is not exactly the expected one. The single support phase finishes at the instant when the front leg touches the ground (with an impact).

Just after the impact of the front leg, the following half step *n+1* begins. At the beginning of this half step, *SemiQuad* has to prepare its rear leg tip to take off. Therefore, initially in the double support of half step *n+1*, *SemiQuad* transfers its mass center forward. Then also in the double support, the rear leg bends in the knee, after it sharply unbends and then bends once more. The rear leg tip looses its contact with the ground and the new single support phase starts with stance front leg. In the single support of half step *n+1*, four torques are applied to the joints to track the reference trajectories. The reference trajectories are designed such that the distance between the leg tips becomes smaller to the end of this next single support. Due to this the rear leg tip moves forward.

To track the reference trajectories we use PD – controller. However, sometime we apply constant torques as it is explained above. In Figure 3, we can see the detailed graph of the torque, which is applied to the front leg knee. This graph corresponds to only one half step of *SemiQuad*. The experimental robot has performed almost thirty five half steps.

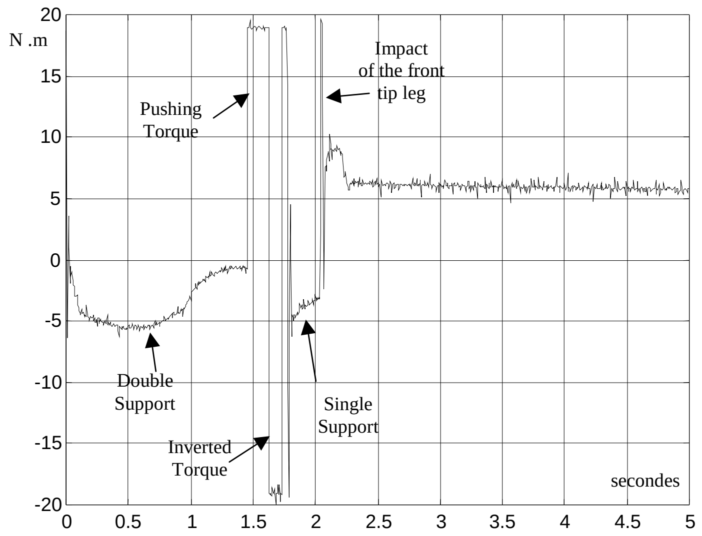

Figure 3. The detailed torque at the knee of the front leg.

6. CONCLUSION

In this paper, we present a walking robot, which is a statically stable in the double support and unstable in the single support. Its motion is planar to illustrate a *curvet* gait of a quadruped robot. This robot has performed first steps. The control strategy mixes the definition of a reference trajectory and its control to the actuated joints. The main difficulties of this control are to define the switching time for each control action because the control algorithm consists of several different parts (for double supports, for single supports).

Currently we are improving our mechanism to obtain a more robust device. We are going also to construct a sensor to detect the instant when the swing leg touches the ground. In the future we hope to include also the force sensors to measure the ground reaction in the stance leg.

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